DEFENCE
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Mar 2003

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Using the Hazard Prediction and Assessment Capability (HPAC) Hazard Assessment Program for Radiological Scenarios Relevant to the Australian Defence Force

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DSTO-CR-0294

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ABSTRACT

Atmospheric hazard modelling programs are used to predict the dispersion and resultant effects from the release of clouds of toxic materials. Both the Hazard Prediction and Assessment Capability (HPAC) and HOTSPOT are models that can be used to estimate hazards arising from the release of radiological material. A comparison of the two models is undertaken, with strengths and limitations of each model discussed. A recommendation is made that the ADF employ HPAC to model radiological hazards.

RELEASE LIMITATION

Approved for public release

Published by

DSTO Platforms Sciences Laboratory
506 Lorimer St
Fishermans Bend, Victoria 3207 Australia

Telephone: (03) 9626 7000
Fax: (03) 9626 7999

AR-012-736
March 2003

APPROVED FOR PUBLIC RELEASE

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Executive Summary

Atmospheric hazard models are used by emergency response managers to predict the effects of a chemical, biological or radiological (CBR) incident. Estimates of the location and extent of high-risk areas and their progression with time are vital in making evacuation decisions. During post-release clean-up operations any residual hazard that may still be present needs to be estimated.

The Australian Defence Force (ADF) employs the Hazard Prediction and Assessment Capability (HPAC) model to aid assessment of chemical and biological (CB) hazards. HPAC, developed in the United States by the Defense Threat Reduction Agency (DTRA), uses high-level mathematics to model the dispersion of CBR materials through the atmosphere, and predict casualties and fatalities based on these calculations.

Due to recent world events, it has become increasingly important to be prepared to respond to the use of radiological weapons, such as the well-publicised radiological dispersion device (RDD), or "dirty bomb." The latest version of HPAC (4.0.1) includes a comprehensive radiological modelling capability but is not yet used for this purpose in Australia. HOTSPOT, a model developed in the United States by Lawrence Livermore National Laboratory (LLNL), is currently in use in Australia for modelling radiological scenarios. HOTSPOT is a very simple model that is not applicable for incidents with complex terrain or variable weather.

The purpose of this report is to review the capability of HPAC to model radiological scenarios that may be relevant to the ADF and other emergency responders. A comparison of the results of HPAC and HOTSPOT has been undertaken and their capabilities and limitations have been reviewed.

HPAC was found to perform favourably for the simple scenarios that HOTSPOT is designed for, as well as having the capability to model much more complex scenarios. The addition of a comprehensive radiological modelling capability to HPAC 4.0.1 makes it the ideal choice to model all CBR hazards using the one platform.

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Contents

1. Introduction

When a chemical, biological or radiological (CBR) incident occurs, those responding need a reliable and timely assessment of the hazard. Estimates of the position of "hot" (high-risk) areas and their likely spread over time are vital in organising a response, and in helping to make appropriate decisions concerning matters such as evacuation. Atmospheric dispersion models are used to predict the progression of a plume of hazardous material in the air. However, the models must not only be able to predict the initial dispersion of the material, but also include an estimate of any subsequent hazards. For example, in a chemical incident the initial cloud of gas and liquid will be modelled, but the evaporation of liquid that settles on the surface needs to be taken into consideration as well. When the hazard is radiological it is important to model the initial cloud, the settling of particles out of the atmosphere and the subsequent hazard that this deposition poses due to ionising radiation emissions.

This report provides an assessment of the application of the Hazard Prediction and Assessment Capability (HPAC) model to radiological scenarios, with a focus on its advantages and disadvantages compared to other models.

2. Hazard Models for Emergency Response Managers

2.1 Models Used in Australia

There are many different atmospheric dispersion models currently in use in Australia for emergency response management. Examples include ALOHA and AUSTOX, which were designed to model releases of toxic industrial chemicals, and AUSPLUME, used to model pollutants.

ALOHA was jointly developed in the United States by the National Oceanic and Atmospheric Administration, and the United States Environmental Protection Agency. ALOHA has a detailed chemical library, and is widely used in Australia and overseas. For a web-link containing details on ALOHA, see [1].

AUSTOX was developed by Monash University in the early nineties to model releases of industrial chemicals. Both AUSTOX and ALOHA were designed to model short-term releases of dense gases, with high concentrations at ground level. A technical description and performance evaluation of AUSTOX can be found in [2] and [3] respectively.

AUSPLUME, developed by the Victorian Environmental Protection Agency (EPA) in 1986, is used to monitor air quality. Contact details for information on AUSPLUME can be found on the website [4].

Unfortunately, none of these models has any capability to model radiological scenarios, as they cannot assess radiation doses, and hence will not be discussed further.

The most commonly used radiological consequence assessment model is HOTSPOT, which is used by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) as an emergency response tool. Developed by Lawrence Livermore National Laboratory (LLNL) and first released in 1985, HOTSPOT gives results quickly and is very easy to use. The two versions of HOTSPOT currently available are 2.01 (2002) and 8.03 (1999), which are Windows and DOS based respectively. There are few differences between the two, although the Windows based version has a slightly more modern Graphical User Interface (GUI) and a better mapping capability. The user manual [5] contains details on the use of HOTSPOT.

2.2 Limitations

All of the above models use a basic Gaussian puff/plume method to model the transport of the material in the atmosphere. This method is very well established and calculations are made extremely quickly, but there are limitations. Complex meteorology and terrain are not incorporated, resulting in low accuracy for some situations. It should be noted that these simple models provide a starting point for analysis of a release, but more detailed models should be used if higher accuracy is required. The HOTSPOT on-line user documentation suggests that the estimated dose at any point has an approximate standard deviation of a factor of five. In other words, 68% of the time we expect the estimated dose at any point to be within a factor of five of the actual dose. Appendix A of [5] contains details of the Gaussian model algorithms.

It is appropriate to use HOTSPOT for hazard predictions over short time-spans only (less than 24 hours), as the meteorological data input is limited to wind speed and direction and atmospheric stability only. Terrain is only accounted for using a generic surface roughness factor, which varies from 0.1m (rural) to 1m (urban). This is generally used on the rural setting when worst-case predictions are required.

HOTSPOT assumes that the activity median aerodynamic diameter (AMAD) is one micron (i.e. 50% of the activity is in particles with a diameter of less than one micron, 50% is in particles with diameters larger than one micron), which means most of the release will be small enough to be respirable. For a radiological dispersion device (RDD), the HOTSPOT default assumes that 20% of the amount of material used is dispersed, with an AMAD of 1 micron.

HOTSPOT output is limited to inhalational doses only; all ground shine doses (i.e. external doses arising from ground contamination) are ignored since inhalational doses are usually much larger (several orders of magnitude) than ground shine doses. Doses are calculated for individual organs, as well as a 50 year Committed Effective Dose Equivalent (CEDE). Deposition data is calculated, but other output such as dose rates,

casualty estimates, etc, are not available. Note that in HOTSPOT all ionising radiation as a result of deposition of radioactive particles is ignored. Therefore, while HOTSPOT is useful for estimating impact upon health from the initial dispersion, it has little value in the subsequent management of the incident as the ongoing contamination from the deposited material is not calculated.

Graphics of contour "footprints" are in *.bmp or *.pcx format, and can easily be copied to the clipboard for pasting into a document or printing.

2.3 Radiological Scenarios Available

HOTSPOT supports the modelling of many different types of radiological scenarios. These include a general explosion, which models the dispersion of a radionuclide (it is also possible to model a mixture of isotopes) using explosives. Other scenarios include the fire, general plume and re-suspension source terms, which calculate the release of radioactive material from a fuel fire, a continuous or puff release or an area contamination incident. There are a number of isotopes that can be modelled, and more can be added if the dose factors are known.

HOTSPOT can also be used to model a nuclear explosion, given only visual data such as cloud top and cloud width angles from an observer a known distance from the detonation. Reliability of the results is not high, since fallout may take days to arrive and only a single wind speed and direction is input into HOTSPOT. Other scenarios include the release of weapons grade plutonium or uranium by fire, explosion, etc.

3. The HPAC Model

3.1 Background

The Hazard Prediction and Assessment Capability (HPAC) has been used to model numerous CBR scenarios since the mid 90's, including the Atlanta Summer Olympics in 1996, 2002 Winter Olympics in Salt-Lake City, and in 1997 and 2001, the United States Presidential Inaugurations.

In Australia, HPAC provided CB modelling for the ADF support to security of the Commonwealth Heads of Government Meeting (CHOGM) in Brisbane in 2002. Other current users of HPAC in Australia include some state fire and emergency services.

HPAC has an interesting structure in that it is designed for two very different types of users - operational and analytical. Operational users are those responding to actual events, and define a scenario in terms of the incident. Analytical users tend to employ HPAC for research and development purposes, and define a scenario in terms of the release parameters. Incident models let the user describe a release in terms of where, what and when. The release information is calculated and then passed to the transport

model that models the dispersion. The transport model is called the Second-Order Closure Integrated Puff model, or SCIPUFF. Instead of using the Gaussian algorithms used in HOTSPOT and other models, SCIPUFF models dispersion based on second-order turbulence closure theory. The concentration field is represented by a collection of Gaussian puffs, with expected or mean concentrations available at any point. However, due to the second-order nature of the method, statistical variance in the concentration field can also be calculated. This gives HPAC a huge advantage over other models as it can provide not only an estimate of the dispersion of the material, but place probabilistic limitations on the accuracy of the prediction. The technical document [6] contains more detail about SCIPUFF.

3.2 Limitations

In many radiological scenarios the contamination of an area is of high concern. HPAC has the ability to reliably model the deposition of radioactive material to the surface, and estimate any residual hazard that this poses.

HPAC has the capability to include terrain, land-cover and detailed meteorological data for increased accuracy, but can also be used without any of the above, making it quite flexible in operational use. For example, early in an incident, HPAC can be used to give initial estimates of likely hazards, and can be rerun quickly when more data (source, meteorological, etc) is available.

Included with the HPAC installation discs is the Digital Terrain Elevation Data (DTED), a worldwide database of terrain elevation using a resolution of 30 arc second squares (approximately 1 km^2). The National Imagery and Mapping Agency (NIMA) produced the DTED database, which was then reformatted and compressed for use by HPAC. The coarse resolution of this terrain data makes it most appropriate for scenarios that cover a large area, but of limited usefulness for smaller scenarios.

There are numerous different types of output that HPAC can produce in a radiological scenario, including dose rates, concentration and deposition levels, doses to various organs, and even casualty and fatality estimates. The casualty predictions are based on the LandScan Global Population 1998 Database, compiled by the Oak Ridge National Laboratory, and having a resolution of 30 arc second squares. Unlike most population databases, LandScan data is not based on traditional night-time residence information, but incorporates diurnal movements and travel habits into a single measure. So, a busy road with lots of night-time lights, while having zero population according to national census data will have some population (based on the size of the road and the intensity of the lights) in the LandScan database. Note that the estimated figures for Australia's population are based on 1996 census data. For more details on the mechanics of LandScan, the on-line document [7] is recommended.

In HPAC an urban environment is approximated using a general surface roughness coefficient to simulate buildings, with all effects of individual buildings on the wind-

flow ignored. An updated version of HPAC containing a validated urban wind-flow module is expected to become available in 2003 and will allow HPAC to predict hazards in an urban environment more reliably.

3.3 Supplying Additional Data

For best results of dispersion, HPAC requires detailed meteorological data, such as surface observations of wind speed and direction, temperature, pressure, cloud cover and atmospheric stability. For large domains, where the hazardous material is likely to reach high into the air, profiles of the upper air conditions are also required. HPAC can also include weather forecasts to give emergency responders a prediction of the extent of travel of the hazardous material.

As mentioned previously, terrain, land cover and population data are included with HPAC, but these will not be adequate for some scenarios. If the terrain is quite complex, or the domain of the release very small, then higher resolution data will be needed to maintain a realistic prediction.

3.4 Radiological Scenarios Available

HPAC has four different types of incident module for use in modelling radiological scenarios. Each of these is discussed below.

3.4.1 Nuclear Weapon Detonation

The Nuclear Weapon (NWPN) module calculates the initial cloud of dust and radioactive material following detonation. This is based on user input of yield estimates, height of the explosion above ground level, etc. The plume is then passed to SCIPUFF, which models the resulting fallout. Also included are estimates of blast, heat and overpressure effects.

3.4.2 Nuclear Weapon Incident

The Nuclear Weapon Incident (NWI) module models the release of weapons grade plutonium dispersed by fire or explosion without nuclear detonation. The user inputs the mass of plutonium and the propellant parameters, which are used to calculate the plume. SCIPUFF is then used to calculate the dispersion and its effects.

3.4.3 Radiological Weapon Incident

The Radiological Weapon (RWPN) module is used to model the effects of an RDD. The calculation of the plume is based on the input of explosive and radionuclide mass. There are only 18 isotopes supported and a mixture cannot be used. Various common forms of each isotope are included, such as salt/powder, ceramic/oxide and metal, providing more realistic estimates of the amount of material released. Nine particle

size bins are used in the explosive cloud, a significant improvement from previous versions of HPAC.

3.4.4 Nuclear Facility Incident

The Nuclear Facility (NFAC) incident module is the most versatile of the radiological components of HPAC. In its normal form it models the release of radionuclides from an incident at a nuclear facility. The database contains detailed information on almost every nuclear facility in the world, including those currently under construction. These details include radionuclide inventories, safety systems and the plant structure.
NFAC can also be used to model a release of any mixture of isotopes using either a constant release rate or a percentage of the total inventory of the facility.

4. Other Radiological Assessment Models

There are many other models that are widely available for use in radiological hazard assessment modelling. Some of the models examined in compiling this report are mentioned here. More information about all of these models can be obtained from the EPA website [8].

COMPLY, developed by the National Council on Radiation Protection and Measurements (NCRP) in 1985, is used for long-term continuous releases from stacks and vents, with calculations based on the Gaussian plume model. It has been widely used to test compliance with EPA air quality regulations in the United States.

The Prediction of Radiological Effects Due to Shallow Trench Operations (PRESTO) is another model used to assess radiological hazards. This is primarily used to model the transport of radionuclides in soil and water over long time periods, and the likely effects on health. It is usually employed to predict the levels of radiation associated with radioactive waste.

CAP88PC was primarily designed for modelling low level, long-term releases, and is similar to COMPLY. CAP88PC has more flexibility with meteorological inputs than COMPLY, but is not designed for high level or short-term releases. Calculations are based on the Gaussian plume model, with effective dose equivalents estimated. Some ability to predict population exposure is also included, although this is quite difficult to use.

It is quite clear that none of the models above are suitable for assessing radiological hazards by the ADF, so the focus will now be restricted to HPAC and HOTSPOT.

5. Comparison of HPAC and HOTSPOT

To gain a better understanding of the different capabilities of the models, two short scenarios were modelled and the results compared. Note that the quantities of radionuclides modelled are very large and are chosen to produce dose contours of a reasonable size.

5.1 Scenario #1 – Radiological Dispersion Device (RDD)

The RDD modelled consisted of a small amount of a long-lived isotope released with a large amount of explosives. Inhalational doses were calculated for several points downwind, and the results compared.

The device contains 6.475×10^{12} becquerel (175 curie) of Americium-241 (Am-241). Am-241 has a half-life of around 430 years and is an alpha emitter. Am-241 is widely used in smoke detectors, although in very small quantities (usually in the order of kBq or µCi). Other uses for Am-241 include crystal research and as a target element in nuclear reactors. See the fact-sheet [9] or the website [10] for more details on Am-241. The Americium-241 is in a salt or powder-like form, and is dispersed using approximately 23 kg (50 lb) of TNT. The resultant cloud of dust, debris, etc, contains around 10%, (approximately 5 grams) of the Am-241.

The release occurs in a rural environment during a mild morning with no cloud cover and a light breeze. Assuming an average breathing rate of 20 litres of air per minute, the calculation of the downwind dose is made after 24 hours of constant conditions. Note that the doses are the Committed Effective Dose Equivalent (CEDE), which can be interpreted as the amount of dose expected during the 50 years following exposure by inhalation, assuming no steps are taken to accelerate the removal of contaminates from the body. Full details of the parameter definitions can be found in Appendix A.1.

Assuming that the meteorological conditions are constant throughout the domain of the calculation, HOTSPOT and HPAC were used to model the dispersion and the results were tabulated in Appendix A.2. HOTSPOT is a deterministic model, in that it will predict the hazard as best it can, whereas HPAC is a probabilistic model and will predict the hazard as well as provide a measure to the uncertainty of the result. This aspect of HPAC highlights the possibility that a small proportion of the exposed people may be exposed to significantly higher or lower doses than the HPAC mean or the HOTSPOT estimate. To give a more reasonable comparison between the two models, the dose that we would not expect to exceed in 2.5% and 97.5% of cases for each point was calculated, and is included in Appendix A.2.

Figure 1 below shows the relation between the results for the two models graphically. Note that the vertical bars on the HPAC curve represent the 95% confidence interval of

the HPAC results, clearly illustrating the variability possible when modelling a scenario using limited data.

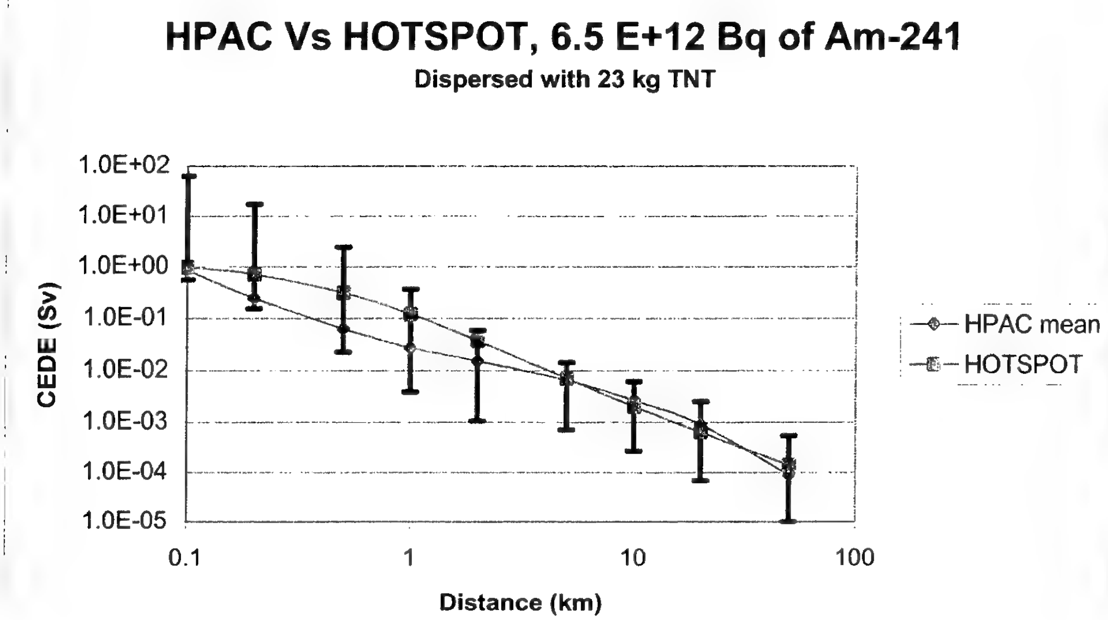

Figure 1: HPAC and HOTSPOT dose versus downwind distance plot. Note the larger differences close to the source, where more uncertainty in the result exists.

To obtain a clear indication of the differences in dose between the two models, it is important to note the logarithmic scales shown in the plot. The two dose curves are quite close together, and no HOTSPOT point is outside the HPAC 95% confidence interval. However, there are large differences between the two from about 100 metres to 2 kilometres downwind (as much as a factor of 5). This corresponds to the area with greatest relative variability in the HPAC results, and given the uncertainty of the Gaussian plume model, is not altogether surprising.

5.2 Scenario #2 - Covert Dispersion

The second scenario was carried out to compare results from modelling a short-lived isotope released without the assistance of explosives.

The device consists of 1 gram of liquid Iodine-131 (I-131), having a total activity of 4.588×10^{15} becquerel (124,000 curie). I-131 is primarily a beta emitter, so minimal shielding would be required to transport it. The half-life of I-131 is around 8 days and it is widely used in hospitals, both for thyroid function tests and cancer treatment, as well as plasma level tests. See [11] and [10] for a book and website respectively with more information.

The I-131 is dispersed from a height of two metres above ground level on a cloudy morning in a rural environment. It is assumed that all of the Iodine-131 will be released into the atmosphere, and transported downwind. Appendix A.3 contains the table of parameter definitions.

HOTSPOT and HPAC were used to model the scenario, again making the assumption that constant meteorological conditions prevail. The CEDE was calculated at nine sensor locations as in scenario #1 above, and the results tabulated in Appendix A.4. The HPAC mean and HOTSPOT estimates for the dose were compared, with the 2.5% and 97.5% levels included to give a better indication of the likely dispersion.

Figure 2 below shows the relation between the results for the two models graphically. Note that the vertical bars on the HPAC curve represent the 95% confidence interval of the HPAC results, clearly illustrating the variability possible when modelling a scenario using limited data as in both these cases.

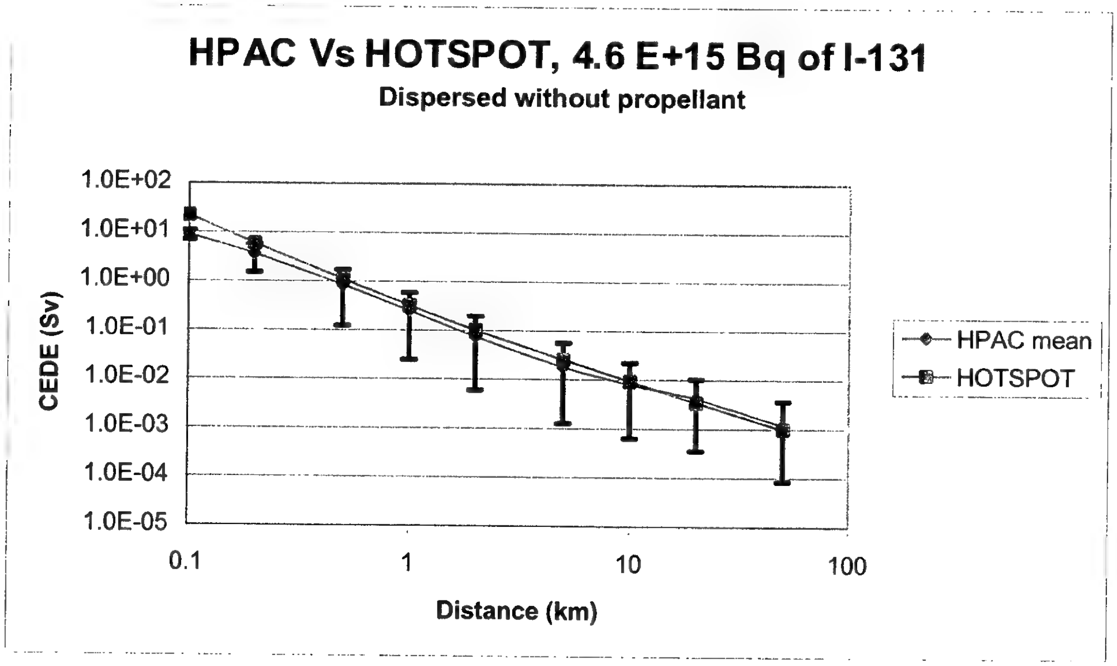

Figure 2: Dose versus downwind distance plot for Scenario #2 modelling.

Again, to make meaningful comparisons between the two dose curves, it is important to note the logarithmic scales of the axes. In this scenario the two curves are much closer together, indicating good agreement between the two models. However, the first point, corresponding to a distance of 100 metres downwind, sees the HOTSPOT value clearly outside the 95% confidence interval calculated by HPAC. The main contributing factor is the low variability in the HPAC calculation close to the source.

The two doses differ by a factor of approximately 2.5, which is well within the uncertainty limits present in the Gaussian plume model (a standard deviation of a factor of five is estimated for HOTSPOT in the user documentation).

5.3 Reliability of Results

Both HOTSPOT and HPAC have been widely used for hazard modelling for many years. Both have been well validated ([12] and [13] contain verification and validation documentation for HOTSPOT and HPAC respectively) and are in use in many countries throughout the world. However, it is well understood that due to the more detailed wind field models that are used in the transport and diffusion model SCIPUFF, HPAC has the ability to provide reliable results in scenarios with complex terrain or under changing weather conditions.

Despite the major differences in the transport and diffusion models used in HPAC and HOTSPOT, the results of very simple scenarios are similar. This reinforces the point that while HPAC is able to model complex scenarios, it can also be used to model simple scenarios, such as those commonly modelled using HOTSPOT.

5.4 Speed of Calculations

In an operational situation it is important to obtain useful results as quickly as possible. HOTSPOT is particularly good in this sense, as it takes only moments to input the scenario parameters, and results are calculated virtually instantaneously. For simple scenarios like those modelled in this report, data input into HPAC takes up to 60 seconds for an experienced user, and calculation is usually completed in around 30 seconds. To produce a contour plot takes only 5 to 10 seconds, but extracting dose data at specific point takes longer. To summarize, the total time for a HOTSPOT run is usually only 15 to 30 seconds, but from 1 to 2 minutes for a similar scenario in HPAC. For HPAC scenarios with complex terrain, highly variable meteorology or large amounts of material, run times vary from about 1 to 10 minutes. Most of the time taken is in setting up the terrain and meteorology files, and adjusting output defaults. The time it takes to do this is really dependent on the situation and the level of complexity involved.

HOTSPOT is a very small program, and can be run on virtually any computer, whereas HPAC requires a relatively modern computer to model detailed scenarios. Computers with a higher processor speed and more memory will be able to model complex scenarios much more quickly. The computer used to derive the time estimates detailed above had a Pentium III 800 MHz processor with 512 MB RAM.

Given the timeframe for a response to an emergency (including the time it will take to alert a modeller), the variation in speed is unlikely to be significant.

5.5 Ease of Use and Required Training

To use either of the programs effectively, some understanding of the atmospheric processes involved in dispersion is required. HOTSPOT is very user-friendly, and prompts the user for the required information, such as the isotope, mass of explosives and meteorological conditions, giving practical advice on parameter selection where appropriate. HPAC requires more training, and a far better understanding of the processes involved, but is still relatively easy to use.

HPAC output is much more useful, with a number of graphics packages supported to overlay contour maps directly on to media such as road maps and aerial photographs, greatly assisting the decision making process. HOTSPOT contours are restricted to being copied as a picture file to the clipboard for pasting into a document or the like.

HOTSPOT's size makes it quite appealing for the new user, with a simple user-interface and prompts for the required information. HPAC is quite good in this respect but its size and complexity can be daunting to the unfamiliar user.

6. Radiological Scenarios for the ADF

Both HOTSPOT and HPAC were designed in the United States for use primarily in the United States. In Australia we have specific requirements of a radiological hazard assessment model. The next section of this report looks at the capabilities of each model with a particular focus on the relevance to the ADF.

6.1 HOTSPOT Capabilities

HOTSPOT models all releases as a short continuous release; the user has no control over the release time. This may limit the model's usefulness, as long continuous releases cannot be modelled accurately. The progression of the hazardous cloud downwind cannot be tracked with any accuracy, as all time-of-arrival estimates are based on mean wind speed only. Since variability in wind speed and direction cannot be accounted for, the model should only be used to predict minimum safe distances from the source. The units of activity and dose may be either the classic curies and rems or the SI units becquerels and sieverts.

Natural radioactive decay of the isotopes is accounted for in the model and is particularly important for releases of short-lived isotopes. Early in the modelling of an incident, it is unlikely that information about the isotope/s released is available. In this situation, the selection of a long-lived isotope such as Americium 241 is recommended.

All deposition and dose outputs are calculated at the end of the dispersion. As such, it is not possible to track the progress of the plume over time. Another consequence of this is that HOTSPOT has no capability to estimate radiation dose rates. Ground

contamination is modelled by deposition, but there is no easy way to extract information on the level of hazard posed by this deposited material.

6.2 HPAC Capabilities

HPAC will model both continuous and instantaneous releases, from point or area sources. It will not model a moving release of radioactive isotopes, although this is possible with a chemical or biological release. All radiological release scenarios are first modelled by defining the incident. The program calculates the initial plume based on user input, and passes it to the transport model SCIPUFF. All radioactive decay of isotopes, including daughter products, is accounted for during the dispersion. Unlike the HOTSPOT program, all radiation received externally (not via inhalation) can also be calculated, which will be crucial for deciding what post-release activities are undertaken in terms of clean-up and decontamination. The radioisotope activity that is given to the model may be in either curies or becquerels, but equivalent dose data is given in rems. To produce equivalent doses in terms of the SI units sieverts, the multiplicative factor 0.01 must be input manually.

The path followed by the plume can be tracked and predicted over time, as can the dose and deposition. This is very easy to do graphically using the animation option, which produces a sequence of images to allow the user to get a clear picture of the predicted dispersion. To produce estimates of the dose at a set of points over time is a little more time-consuming. The level of uncertainty in the prediction can also be estimated in a graphical format, as well as other predictions, such as casualty and fatality estimates. Both models can provide estimates of the area contaminated with a certain level of radiation.

There is no isotope with zero decay, so choosing a long-lived isotope such as Americium 241 is recommended if no information on the isotope is available.

Nuclear weapon effects modelling is currently of reduced concern in Australia. However, fallout from a nuclear blast can travel such vast distances that a capability to model its progress is useful. For example, in the event of the detonation of a nuclear weapon, HPAC can provide a prediction of the effect of transcontinental drift.

The Radiological Weapon source term is ideal for modelling the use of an RDD. Current concerns with terrorism around the world make it important for the ADF to have a capability to predict the effects of such an attack.

The Nuclear Facility Incident module could be used in two ways in Australia. The first application would be to model an incident at Australia's nuclear reactor at Lucas Heights. HPAC has a built-in database containing information on the Lucas Heights reactor, such as the amount and type of radioactive materials it contains, although the accuracy of this information was not examined for this report. Any incident at this reactor can be modelled by HPAC to provide an estimate of the effects.

The other major application of this source term in Australia would be to model the release of radioactivity without explosives. This could happen quickly, as in scenario 2 of the comparison between HOTSPOT and HPAC, above, or much more slowly. A typical situation could be an accidental release or possibly a terrorist attack. This module would also be useful when a mixture of isotopes is known to have been released, as the other source terms do not readily permit modelling of a mixture with multiple isotopes.

7. Conclusion

HPAC is far more flexible than HOTSPOT, as it can progressively build up the complexity of a situation as more details on the release are gathered. HOTSPOT is limited to providing an initial estimate of the hazard only. Other more complicated transport models, such as Computational Fluid Dynamics (CFD) methods, lose the advantage of increased accuracy to massive increases in run times. HPAC appears to provide a useful balance between complexity and speed.

When modelling the effects of an RDD with either HOTSPOT or HPAC, the need to provide an estimate of the amount of explosives (in kg TNT) based on appearance of the initial cloud is very important. HPAC will operate with the same limited meteorological data used by HOTSPOT and provide similar results, as shown in the results of the comparison carried out as part of this report. However, HPAC can also provide far more realistic predictions, incorporating the effects of terrain, land usage and surface and upper-air meteorology. HPAC's wide range of output data and plots, such as casualty prediction, deposited hazard, dose and dose rates provide another example of the advantages in its use. The time difference between HPAC and HOTSPOT in modelling simple scenarios was found to be in the order of a few minutes, which may not be significant in an operational sense.

HOTSPOT could still be useful in an operational situation, mainly due to its size and ease of use. Other advantages include its portability and the limited training users require to operate it. However, HPAC is already in use and is widely considered to be the primary software for the modelling of CBR hazards. HPAC has been successfully used throughout The Technical Co-operation Program (TTCP) nations and other countries. Australia successfully employed HPAC during CHOGM in 2002 to model chemical and biological scenarios. The latest version, HPAC 4.0.1, has a much improved capability for the modelling of radiological incidents, and so provides a complete CBR hazard modelling capability using a single platform. It allows the user to model a wide range of CBR incidents or releases and obtain a variety of outputs to facilitate their analysis. The utility of HPAC will be enhanced by the planned addition of an urban dispersion capability into the HPAC suite. A new version of HPAC (4.1), containing a fully validated urban dispersion capability, is expected to be released late in 2003.

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Appendix A: Summary of Modelling

A.1. Scenario #1 – Parameter Definitions

Release		
	Activity	= 6.475 x 10^{12} becquerel (175 curie)
	Isotope	= Am-241
	Mass	= 51.02 grams
	Particle Sizes	= 1 m AMAD (HOTSPOT), 9 part. Sizes (HPAC)
	Released Fraction	= 10%
	Form of Material	= Salt/Powder (HPAC), N/A HOTSPOT
	Explosives Used	= approximately 23 kg (50 lb)
Location		
	Lat/Lon	= 38 S, 144 E
	Date & Time	= 01/07/2002, 0000UTC
Weather		
	Wind Speed	= 1 m/s wind
	Wind Direction (from)	= 270 degrees
	Wind Reference Height	= 2 m above ground level
	Temperature	= 20° C (HPAC), N/A HOTSPOT
	Cloud Cover	= Clear
	PGT[1] Stability	= A (Extremely Unstable)
Calculation Parameters		
	Sensor Height	= 0 m
	Inhalation Rate	= 20 l/min
	Output	= CEDE Inhalational Radiation Dose only
	Length of Calculation	= 24 hours

Appendix A.1 Notes:
1 - Pasquill Gifford Turner (PGT) stability class is a measure of atmospheric stability. For a more detailed explanation, DSTO General Document [14] is recommended

A.2. Scenario #1 – Table of Doses

CEDE Inhalational Doses (Sv)				
	HPAC 4.0.1			HOTSPOT
Distance (km)	Mean	2.5%[1]	97.5%[2]	Estimate
0.1	0.841	0.555	63.021	0.980
0.2	0.245	0.152	17.238	0.700
0.5	0.063	0.022	2.418	0.310
1	0.027	0.004	0.363	0.120
2	0.015	0.001	0.058	0.037
5	0.006	0.001	0.014	0.007
10	0.003	0.000	0.006	0.002
20	0.001	0.000	0.002	0.001
50	0.0001	0.0000	0.0005	0.0001

Appendix A.2 Notes:
1: Value such that we predict only a 2.5% probability of lower dose at a point.
2: Value such that we predict a 97.5% probability of lower dose at a point.

A.3. Scenario #2 – Parameter Definitions

Release		
	Activity	= 4.588×10^{15} becquerel (124,000 curie)
	Isotope	= I-131
	Mass	= 1.0 grams
	Particle Sizes	= N/A (HPAC), 1 m AMAD (HOTSPOT)
	Released Fraction	= 100%
	Form of Material	= Liquid (HPAC), N/A HOTSPOT
	Height of Release	= 2 m above ground level
Location		
	Lat/Lon	= 38 S, 144E
	Date & Time	= 01/07/2002, 0000UTC
Weather		
	Wind Speed	= 4 m/s
	Wind Direction (from)	= 270 degrees
	Wind Reference Height	= 2 m above ground level
	Cloud Cover	= Overcast
	PGT Stability	= D (Neutral)
Calculation Parameters		
	Sensor Height	= 0 m
	Inhalation Rate	= 20 l/min
	Output	= CEDE Inhalational Radiation Dose only
	Length of Calculation	= 24 hours

Appendix A.3 Notes:

1 - Pasquill Gifford Turner (PGT) stability class is a measure of atmospheric stability. For a more detailed explanation, DSTO General Document [14] is recommended

A.4. Scenario #2 – Table of Doses

CEDE Inhalational Doses (Sv)				
	HPAC 4.0.1			HOTSPOT
Distance (km)	Mean	2.5%[1]	97.5%[2]	Estimate
0.1	8.885	6.909	10.861	22.000
0.2	3.558	1.502	5.620	5.900
0.5	0.836	0.121	1.706	1.100
1	0.248	0.024	0.583	0.320
2	0.073	0.006	0.193	0.100
5	0.018	0.001	0.056	0.025
10	0.008	0.001	0.022	0.009
20	0.004	0.000	0.010	0.003
50	0.001	0.000	0.004	0.001

Appendix A.4 Notes:
1: Value such that we predict only a 2.5% probability of lower dose at a point.
2: Value such that we predict a 97.5% probability of lower dose at a point.

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1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)
Using the Hazard Prediction and Assessment Capability (HPAC) Hazard Assessment Program for Radiological Scenarios Relevant to the Australian Defence Force	Document (U) Title (U) Abstract (U)
4. AUTHOR(S) Alexander Hill	5. CORPORATE AUTHOR Platforms Sciences Laboratory 506 Lorimer St Fishermans Bend Victoria 3207 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-CR-0294	AR-012-736	Client Report	March 2003

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
2003/12668	02/085	ARM	18	14

13. URL on the World Wide Web	14. RELEASE AUTHORITY
http://www.dsto.defence.gov.au/corporate/reports/DSTO-CR-0294.pdf	Head, CBRN Defence Centre

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Australian Defence Forces, Hazard Analysis, Radiological Warfare Agents, Biological Warfare Agents, Chemical Warfare, Computer Software, Modelling, Performance Evaluation, HPAC, HOTSPOT

19. ABSTRACT

Atmospheric hazard modelling programs are used to predict the dispersion and resultant effects from the release of clouds of toxic materials. Both the Hazard Prediction and Assessment Capability (HPAC) and HOTSPOT are models that can be used to estimate hazards arising from the release of radiological material. A comparison of the two models is undertaken, with strengths and limitations of each model discussed. A recommendation is made that the ADF employ HPAC to model radiological hazards.